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Facilitating Disaster Knowledge Management with Agent-Based Modelling

Dedi Iskandar Inan
Universitas Negeri Papua, Indonesia School of System, Management and Leadership, Faculty of Engineering and Information Technology University of Technology Sydney, Australia, dedi.i.inan@student.uts.edu.au

Ghassan Beydon
University of Technology Sydney, Ghassan.Beydoun@uts.edu.au

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Completed Research Paper

Dedi Iskandar Inan
Universitas Negeri Papua, Indonesia
School of System, Management and Leadership, Faculty of Engineering and Information Technology
University of Technology Sydney, Australia
dedi.i.inan@student.uts.edu.au

Ghassan Beydoun
School of System, Management and Leadership, Faculty of Engineering and Information Technology
University of Technology Sydney, Australia
ghassan.beydoun@uts.edu.au

Abstract

In developed countries, for recurring disasters (e.g. floods), there are dedicated document repositories of Disaster Management Plans (DISPLANs) that can be accessed as needs arise. Nevertheless, accessing the appropriate plan in a timely manner and sharing activities between plans often requires domain knowledge and intimate knowledge of the plans in the first place. In this paper, we introduce an Agent-Based (AB) knowledge analysis framework to convert DISPLANs into a collection of knowledge units that can be stored in a unified repository. The repository of DM actions then enables the mixing and matching knowledge between different plans. The repository is structured as a layered abstraction according to Meta Object Facility (MOF) to allow the free flow access to the knowledge across the layers. We use the flood DISPLAN of the SES (State Emergency Service), an authoritative DM agency in NSW (New State Wales) State of Australia to illustrate and validate the developed framework.

Keywords: Agent-Oriented Analysis, Metamodelling, Disaster Management, Knowledge Analysis, Agent-Based Model

Introduction

The communication and knowledge-sharing support is critical to enabling negotiation and cooperation in Disaster Management (DM) scenarios. Currently, the agency leading the program to combat the disaster assumes the role of organizing and eliciting the knowledge, and ultimately structuring it in a shareable and reusable format. The knowledge is produced as DM plans that are made available via the web. However, accessing the knowledge specified in a semi-structured natural language format is very challenging. The written knowledge tends to be structured in a business specification format which, in fact, is seen as subjective by the stakeholders. Much analysis may be required to enable development of useful and actionable insights. In this paper, we view the challenge of DM as one of harnessing and sharing knowledge between stakeholders who are involved in the timely and effective reduction of the impact of a disaster. The first step towards this is to revisit the codification of DM knowledge document sources to facilitate the reuse and sharing of the knowledge they contain. But analyzing the written knowledge in a complex domain, such as DM, is not only difficult but also time-consuming (Beydoun et al. 2014; Brown et al., 2016).

Disaster Management Plans (DISPLANs) do not articulate a single goal. Entities involved in a DM activity need to not only react or adapt to the environment, but to also exhibit their local goal formulation (Sword-Daniels et al., 2016). The ability of each entity to recognize the relevant DM knowledge (Dominey-Howes et al., 2014) needs to be encouraged. Critical environment characteristics cannot be controlled and predicted, but awareness of them is essential to facilitate cooperation. Entities/organizations/individuals involved have their own goals, resources and structures. At the same time, the need to communicate and negotiate to pursue common goals is paramount. Identifying the goals of the DM activities of other entities is crucial (Vijitpornkul & Marurngsith, 2015). This will require those others to be involved. To enable all this, there is an imperative for timely sharing and reusing of knowledge.

This paper addresses the challenge of how to convert existing DM knowledge into layers of abstraction to enable a unified point of access. This paper advocates the use of a knowledge repository based on a common MOF modelling framework, the Object Management Group (OMG) (OMG, 2013), and a Disaster Management Metamodel (DMM) (Othman et al., 2014). DMM was originally developed following the use of a MOF rigorous methodology to represent the DM domain according to the three modelling layers: *M0* (real world objects), *M1* (model) and *M2* (modelling language/metamodel). This enables abandoning a timeline sequence in favor of free flow access to any point. The proposed approach converts end user models to concepts and notation from DMM, and relies on Agent-Based (AB) Modelling to achieve this. Agent-Based Models (ABMs) lend themselves to representing organizational know-how and DM processes. They emphasize the constructs of roles, agents and organizations to represent systems' behaviors. With appropriate supporting tools, this knowledge can be deposited and shared using a DMM-based system. The rest of this paper is organized as follows: Section 2 reviews the background and related work. Section 3 presents the framework and shows how to convert extant DISPLAN domain knowledge to DMM constructs. Section 4 illustrates the approach using an actual case study of a DM flood plan of State Emergency Service of New South Wales (SES NSW). Section 5 evaluates the illustration. Section 6 concludes with a discussion of future work.

Related work

A metamodel is a collection of classes to describe domain concepts to represent domain entities, actions or states (Othman & Beydoun, 2013). It is often utilized as a high level knowledge structure that enables the creation of knowledge repositories with an intelligible interface (Quintana-Amate et al., 2015; Sharma et al., 2015). A metamodel thus contains the specification of a modelling environment and defines the syntax and the semantics of the domain (Syriani et al., 2013). Classes and relations in a metamodel represent the set of constructs and rules of how these constructs interact (activities, interactions, conditions, actors, roles, triggers and so on). The development process of a metamodel typically complies with a rigorous and systematic methodology (Whittle et al., 2014). For DM, a specific metamodel, DMM, was developed (Othman & Beydoun, 2013). DMM represents prescient concepts and relations in DM. DMM was developed using 89 extant DM models prescribed by various government, private, and academic efforts as detailed in the work of Othman et al. (2014). The development process of the metamodel aims at completeness and consistency of outcome, and extends a metamodeling process that was used in software engineering of complex systems. The process iteratively reconciles and validates individual concepts and their relations. DMM therefore represents a complete picture of DM, but the level of rigor and detail is left for the users of DMM to apply. For instance, *Deployment*, a DMM concept in the Response phase is defined as follows: "*The process and procedures used by all organizations (including Federal, State and local) for activating, assembling and transporting all resources that have been requested to respond to or support an incident*" (Othman et al., 2014, p. 28). The detailed knowledge of *Deployment* activity will be stored in the knowledge repository location that can be accessed by this concept. This enables partitioning of DM problems into sub-problems easier to manage. It can also provide an easily accessible layered representation of knowledge.

DM modelling aims to capture the complex characteristic of DM and present it in a way common people can easily understand. DM knowledge has four characteristics in common with ABM: (a) *Situatedness* in an environment (Cavallo, 2014). As disasters are dynamic, unpredictable and uncertain, the environment changes rapidly which leads to the second characteristic; (b) *Time sensitivity* (Janssen et al., 2010); in a disaster, every activity has to deal with deadlines, otherwise the consequences might lead to casualties, or even fatalities; (c) *Non-deterministic* (Wex et al., 2011). Disasters often throw up unexpected eventualities. This factor means the level of unpredictability is very high; and (d) *Presence of autonomous entities* (Dawson et al., 2011). This means that in a DM activity, individuals/agencies/organizations are coming from different backgrounds, knowledge, abilities, structure, mandate, with no common perception and so on. ABM enables analysis of complex systems, in particular socio-technical systems (Winikoff & Padgham, 2013).

ABM uses constructs from familiar organizational settings (e.g. roles, activities, interactions etc.) (Miller et al., 2014; Xu et al., 2011). It is at the high-level of abstraction that enables analysts to apply, from their daily deductive processes, concepts with which they are familiar (Winikoff & Padgham, 2013). Furthermore, in both ABM and the context of DM, there are agents driven by local goals that need to interact towards a system goal. Such agents have specified roles and in many instances are situated so they can respond in real time. Not surprisingly, there have been various attempts recently to use ABM to support DM (Mas et al., 2015; Nageba et al., 2014; Wagner & Agrawal, 2014). However, much of these works focus on developing simulations of disaster events to gauge the effectiveness of existing practices.

This paper introduces a knowledge analysis framework based ABM to facilitate modelling and sharing of DM knowledge. ABM templates are used to convert DM knowledge to an intermediate form which can then be mapped to DMM-based constructs. This in turn enables the conversion of DISPLANs to the shareable form that enables DM stakeholders to engage in cooperative decision-making processes. The process exploits the abstraction layering of the MOF framework. The first layer, *M0*, describes how knowledge related to tactical activities are structured. In the next layer, *M1*, knowledge from the *M0* is abstracted and generalized to describe policy and planning contexts. In the *M2* layer, the knowledge is then abstracted in the conceptual level. The relationship between the model's layers is described as an instance, and its classifier (or class and object) (OMG, 2013). The lower layer of MOF is an instance of, and therefore should conform to, its higher layer; otherwise a higher layer would be able to instantiate a model as its lower layer. The lowest level of MOF is the domain being modelled, named *M0*.

Therefore, the model in the higher layer (*M1*) is the model itself, as the resultant of modelling the *M0*. A model in a higher abstraction layer basically represents language to be expressed for the model in the lower level. Thus, with respect to the analogy, the model at *M2*, called the metamodel, is a classifier that represents language for the model of *M1* (instance of). Analyzing DM knowledge sources requires a conceptual tool which includes not only adequate analysis processes, but also structures to guide analysts in identifying those complex characteristics. In the next section, an analysis framework is presented that utilizes AB constructs as a mediating representation between the DM knowledge sources and the structured DMM. DMM is based on the MOF metamodeling framework.

DM knowledge analysis requirements

In general, DISPLANs are created as instances of centrally developed templates, for example those which are developed by the NSW and Victorian SES's State planning policies. The structured DISPLAN knowledge of the cities/municipalities in each State show commonality as they are developed using the same typical template, however there is also local expert knowledge added to each instance. As a template, all the relevant and observable knowledge elements will be included and identified. The template serves as a general guideline to be embraced by agencies to develop their own DISPLANs by adjusting them to their local resources and environments. Eventually, each of the cities themselves will decide which knowledge will be appropriate. In other words, each of the cities will inherit the knowledge from the template and customize it with respect their conditions and situations.

Due to the significant size of the DM knowledge involved, efficiency of analysis is a key requirement. Thus analysis begins with the DISPLAN knowledge template, rather than a unique localized plan. The use of templates as the input instead of a unique plan increases the effectiveness and efficiency of the analysis by first tuning the ABM templates to suit the core structure of all DISPLANs. In this context, effectiveness relates to the adoption of the process in which the modelers producing customized ABMs to able to more quickly generate many instances that are strongly based on the core template but are specific to localized parameters. This mirrors the approach taken by emergency management agencies. Further, templates are a benefit if any ratification of changes or updates occur as these can be promulgated and adapted in any instance of localized plans. Finally, templating is a key approach to effective interoperability as it helps stakeholders to quickly identify the urgent and relevant knowledge to respond to a particular activity by developing a familiar construct of actions which can easily be navigated. This is illustrated in Figure 1.

In the case of a State level DISPLAN, the template can be employed to generate the plans for all municipalities/cities across the State, as they are all under the same hierarchy level. Therefore, all instances automatically conform to their template. For instance, in NSW, Australia, all the cities and regions across the State adopt the same DISPLAN template for flood disaster developed by the SES NSW. The template is developed as a classifier which is used by the NSW SES in each region and its cities to instantiate their specific DISPLANs. These particular DISPLANs adapt and adjust the customized template based on their resources and environments. This can also be observed in other state in Australia, for instance Victoria State, for similar disasters.

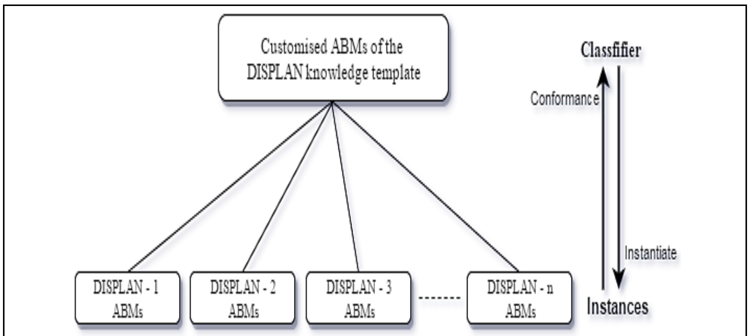

Figure 1. Template and the DISPLANs relationship

Knowledge Analysis Framework

In the first stage of our knowledge analysis framework, the knowledge engineer customizes ABMs with respect the DISPLAN template. The engineer is then able to synthesize and adjust them with respect to the environment and local resources of that city/municipality. The synthesized templates are then transformed into the repository following a specified semantic mapping. The knowledge structured in the repository can then be adopted by the particular city in a disaster event the DISPLAN aims for. The knowledge analysis framework is shown in Figure 2. It consists of three stages, as follows:

Stage 1: The input is customized by seven ABMs that are tightly coupled with the MOF. The input is the DISPLAN knowledge template across all PPRR phases in a semi-structured format. This process results in the customized ABMs of DISPLAN knowledge templates.

Stage 2: The customized ABMs from Stage 1 are used to analyze the DISPLAN template based on the specific local resources and circumstances. This process results in the ABM DISPLANs. In this stage, the repository is also prepared by annotating it. This produces an annotated DMM-based repository that is ready to be used for transformation processes.

Stage 3: This is the knowledge transformation process. It requires that the repository is in place and ready for the depositing processes. In this stage, the ABM DISPLANs produced in the second stage are transferred to the annotated DMM-based repository. A DM expert intervention is normally required to guarantee that the models resulting from the previous stage are mapped and positioned correctly to the appropriate concepts based on the semantic meaning.

The remainder of this section details the stages of our knowledge analysis framework.

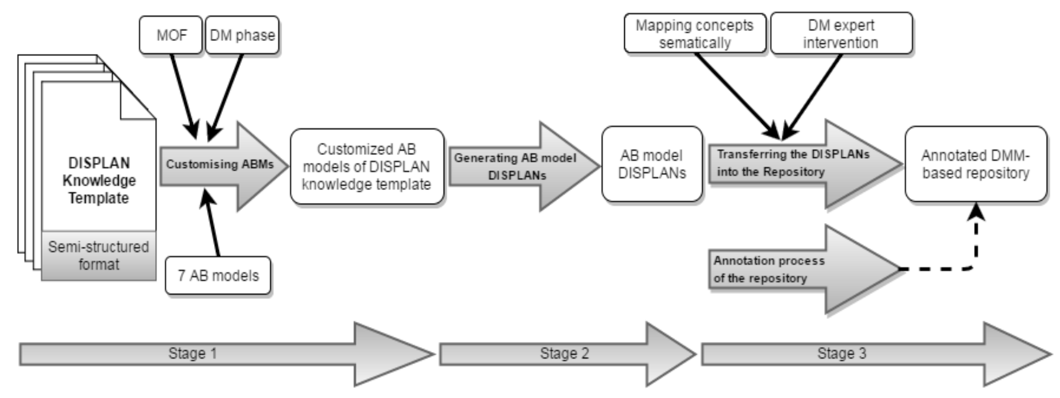

Figure 2. Three main stages of knowledge analysis framework

Stage 1: Customizing Agent-Based Models

A DISPLAN template describes the structure of every DISPLAN. It also has knowledge that is common to all plans, for example contact details within the state or the names of roles. The template is in a semi-structured format and covers all four DM phases. ABMs can represent organizational processes and activities as described in a typical DISPLAN. In this step, the commonalities captured and expressed in the template are transferred to the ABM templates. That is, each ABM templates undergoes four steps in this customization:

1. Common knowledge elements are transferred to the ABMs.
2. Each ABM template is reduced in size to delete elements that are not required. That is, only the required elements are used in the ABMs.
3. Each element in the model is marked as either M0 or M1 (this later acts as a pointer in the transfer in Stage 3).
4. Each element in the model is marked with potential target DMM concepts (this acts as another point in the transfer in stage 3).

Essentially, this process is to use the template of the DM knowledge (the DISPLANS) to extract any meta characteristics to simplify the modelling (in Stage 2) and to simplify the transfer process (in Stage 3). The output of this stage is a set of customized ABM of DISPLAN knowledge templates. We identify the following seven ABM templates to customize to facilitate the capture of the DM knowledge. The details of these models are based on (Lopez-Lorca et al., 2016) and are as follows:

Goal models: The *goal model* represents a particular condition that an agent persistently strives to accomplish. It contains goals/sub-goals and roles responsible for each of them. It describes goals/sub-goals that describe conditions that need to be achieved and the roles (played by agents) for which they are responsible. A *goal model* is introduced to capture the reactiveness and proactiveness knowledge of the agents involved in the DM. In this model, roles that need to be played in order to achieve the goal(s) are also identified. The sub-goals as subsets of the goals are also identified. It describes the proactiveness of an agent. In a DM, all entities (individuals/agencies/organizations) involved in all activities are required to have knowledge about their goals described in the DISPLAN. The customization process for the *goal model* is exemplified in Figure 3.

The *goal model* comprises the main goals and the sub-goals for each condition. The main goal is the goal that needs to be achieved by a set of activities represented as the sub-goals. In a DM, all entities (individuals/agencies/organizations) involved in all activities are required to have knowledge about their goals described in the DISPLAN. A particular goal might be pursued by more than one of the roles played by the agent(s). Sharing responsibility for how a goal should be achieved leads involved agents to refine each of their responsibilities for how they should perform. The consequence of more than one agent performing a goal is that the relationship needs be clear, as they might come from different level of hierarchies and jurisdictions.

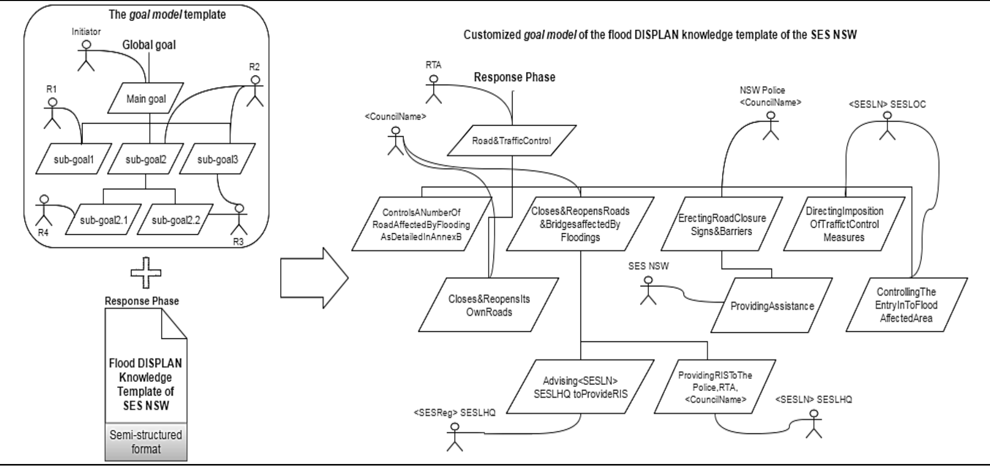

Figure 3. The *goal model* template and a DISPLAN template.

(Note, only *goal model* is shown in this stage due to space limitations).

Stage 2: Generating ABM based DISPLANs

The analysis process begins with generating the *goal model*. The seven adopted ABMs share knowledge elements with each other. The ABMs are generated from the DM plans in a depth-first manner. Once one main goal is completely modelled then a modeler can process the next models. By generating the *goal model* first, and reusing knowledge elements from the *goal model,* the number of revisits to the DISPLAN is reduced rendering the process more efficient. Following the *goal model*, the *role model, organization model* or *interaction model* are generated. These three models can only be completed once the *goal model* is complete. Knowledge elements of these models are linked to the *goal model,* although they are structured differently. The three models are followed by the *environment model* which can only be completed once the *role model* is completed. For instance, the element *role* in the *environment model* needs to be extracted from the *role model*. The *agent model* and *scenario model* are the last two to be completed. The knowledge elements of these two models depend on the content of the other models hence they are generated once all five others are completed.

The analysis process is iterative. It can separate analysis of the main goals and each of their sub-goals. i.e. later activities are identified to support earlier activities. For instance, in Figure 4, sub-goals *g3.1* and *g3.2* support the main goal *g3,* and/or the sub-goals *g3.2.1.1* and *g3.2.1.2* support *g3.2.1,* and so on. This enables a modeler to concentrate on completing one main goal at a time, without being distracted by the other goals/sub-goals. This can significantly reduce the complexities in the early requirement phase. The modeler analyses the main goal *g1,* and all its sub-goals from *g1.1* to *g1.1.1.1*, and roles *R1* and *R3*. All the sub-goals of a main goal can be traced as the activities to support and address the main goal. Since the role *R1* is responsible for the main goal *g1*, it also implies that the particular role is responsible for all the sub-goals of the main goal. Thus, the role *R1* is automatically responsible for *g1, g1.1, g1.1.1* and *g1.1.1.1*. The *goal model* informs that for the sub-goal *g1.1.1*, there is another role, *R3*, involved in pursuing it. This notifies the role *R1* is responsible as the initiator for the main goal while both *R1* and *R3* will interact, communicate and coordinate in pursuing the sub-goal *g1.1.1*. These elements of the *goal model* will be used to identify relationships between related ABMs.

The depth-first approach offers a systematic way to conduct a detailed agent oriented analysis. It shows not only where to start the modelling activities (Lopez-Lorca et al., 2016; Miller et al., 2014; Beydoun et al., 2006) but also how to do it step by step. As shown in Figure 4, once the *goal model* is holistically analyzed and modelled then a modeler can easily look at the model's elements as the cornerstone to process other ABMs without revisiting the knowledge in the document. For instance, the roles involved to pursue a sub-goal analyzed in the *goal model* will be the basis to structure the *organization model* and *interaction model*. The main goal and sub-goals of the *goal model* will be used to structure *action* in the *agent model* and *activity* in the *scenario model* and so on. In addition, these processes themselves are conducted iteratively, therefore the modelers can always go back the previous stage to improve the modelled models. By adopting the depth-first approach, ABM can also be made more efficient by distributing the processes to a number of modelers. In this approach, distributing means that these *modeler*s can share modelling tasks in parallel. The main goals will be placed along the *M1* layer of MOF. They are objectives that need to be pursued in a particular DM activity as they represent the policy/planning knowledge. The sub-goals will be positioned along the *M0* layer of MOF.

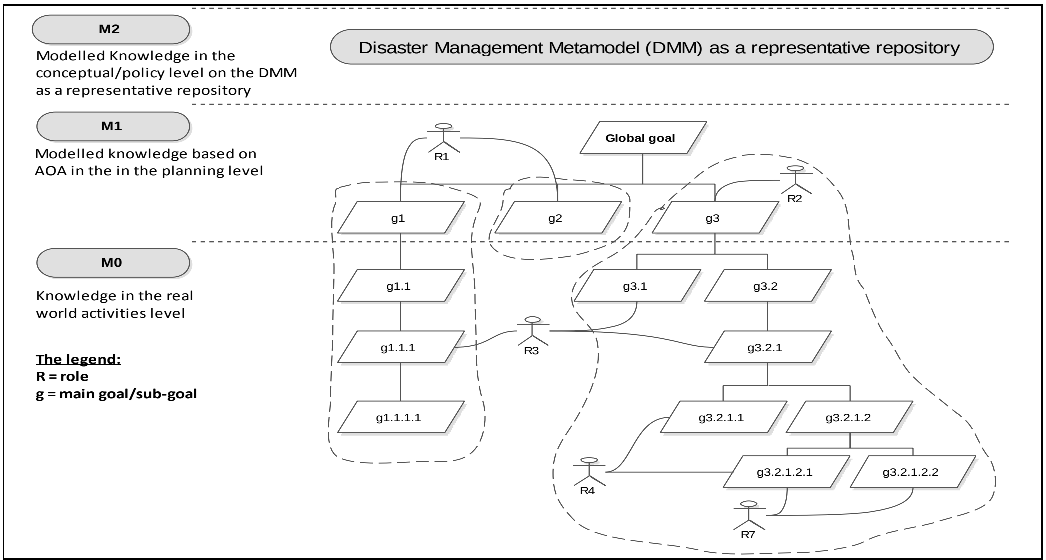

Figure 4. The AOA of a *goal model* in a depth-first search approach

Stage 3: Knowledge transfer

Once the ABMs corresponding to a particular DISPLAN are generated, their content is transferred into the knowledge repository. For this purpose, each concept in DMM is first annotated with pointers to potentially corresponding elements from the ABM. The steps involved are described in what follows.

Annotating DMM concepts with the AO concepts

This step provides the basis of a semantic mapping between the elements of the ABM and the DMM constructs. To ensure that the mapping preserves and is consistent with the abstraction layers defined by the MOF, a corresponding MOF Agent-Based (AB) metamodel, FAML (Beydoun et al., 2009), is used as a basis for the annotation. The FAML metamodel is used to provide a set of terms that are used to annotate DMM appropriately. This mapping between DMM and AB metamodel is a one-off process. It is not a one-to-one mapping. In many case, DMM concepts are annotated with the multiple AB metamodel concepts. That is, DMM concepts contents are sourced from multiple ABMs.

All 92 DMM concepts across all PPRR phases are annotated (21, 25, 25 and 21 concepts respectively in each DM phase). A knowledge modeler is required to link DMM concepts with the appropriate concepts in FAML. The *Evacuation* concept, for example, is defined as follows: "*An organized, phased, and supervised withdrawal, dispersal or removal of civilians from dangerous or potentially dangerous areas, and their reception and care in safe areas*" (Othman et al., 2014, p. 23). This is a set of activities to be undertaken to maintain the skills of DM stakeholders. This consists of a set of activities, hence, the corresponding concept from the FAML metamodel is the <<*Activity*>>: "*Describes a set of activities to be performed to achieve the goal(s)*". Therefore, the modeler annotates *Evacuation* concept in DMM with the <<*Activity*>>. The annotation process produces a 3D knowledge structure that describes those three dimensions: DM phases, knowledge level and the annotated AB metamodel. The structure is readies to be utilized as a representative repository.

Transferring the DISPLAN into the annotated DMM-based repository

In this stage, every ABM acquired in Stage 2 is transferred into the annotated DMM-based representation following the mapping provided in Step 1 of Stage3. This part of the process is the foundation of the proposed knowledge analysis framework, as it allows the DM knowledge in the different conceptual levels to be both synchronized, and traceable for the purpose of the Disaster Management-Decision Support System (DM-DSS). This transforms DISPLANs content to its appropriate metamodel level (*M0 to M2*, with respect to MOF framework). By adopting the MOF in software engineering, tangled knowledge of DM can be pinpointed to the abstraction layer to which it belongs. The activities in this step are undertaken semi-automatically. The process still requires a DM expert intervention by pinpointing the similar concepts semantically at both ends. A DM practitioner is involved in transferring the models to their appropriate DMM constructs.

The ABM elements are mapped to 92 DMM concepts across all phases in the DM. One element maps to multiple DMM concepts. The DM practitioner selects a subset of the possible DMM constructs for each element. They identify which concepts in the DMM-based repository are appropriate to capture the knowledge in the ABMs. To help the DM practitioner pinpoint the DMM concepts appropriately, the categorization based on AO metamodel concepts that can be applied across all phases. Thus, instead of examining all annotated DMM concepts in all phases that match with one in ABM, the annotations automatically help a modeler to narrow the searching process. This is conducted by limiting a set of most likely to-be-appeared concepts based on a particular AO metamodel concept. Eventually, a modeler can map an ABM to the only concept(s) that are semantically similar to it in the repository. The process is evaluated engaging a DM practitioner from SES NSW in Australia. This case study is described in the next section.

Case Study: transfer of NSW Flood DISPLAN knowledge

In this section, the framework of knowledge transfer analysis is evaluated. A case study from SES NSW is used. As earlier described, a DISPLAN template is first acquired. That is a flood DISPLAN knowledge template of the SES NSW acquired as the first input of the framework. This input is used to customize the ABM templates to enable their more effective and efficient use. The templates are then utilized to generate particular DISPLANs and these are then transferred into the repository. The DISPLAN instance aimed to generate is the Wollongong Municipality Flood Management DISPLAN. The Wollongong DISPLAN, the focus of this case study, is maintained to prepare for, manage the response to, and support recovery from flood disasters. It is maintained by SES NSW in conjunction with the Wollongong City Local Government and its representative Local Emergency Management Committee, comprising local stakeholders. The original plan can be downloaded freely from the SES' website, www.floodsafe.com.au. The plan covers knowledge in three phases: Preparedness, Response and Recovery. The modelling process shown in this research is applied only to the Preparedness and Response phases, representing pre- and post-disasters. The three stages of the transfer process for the Wollongong DISPLAN are illustrated in details in this section.

Stage 1: Customizing Agent-Based Models

In this stage, the seven ABMs are customized. The flood DISPLAN knowledge template of SES NSW is analyzed and to identify commonalities and model the commonalities into the ABM templates. In what follows, the customization of some of the ABM templates is elaborated according to the two steps (not all are shown due to space limitation).

Customizing the goal model: A main goal is identified. The goal "*Road and Traffic Control*" is identified as an example from the SES flood DISPLAN knowledge template in NSW. All instances produced from this customized *goal model* will subsequently contain this knowledge as class of a main goal. Once this goal is identified, the knowledge engineer then goes through the document to identify all other related knowledge elements for this particular main goal only, namely its sub-goal(s) and role(s), and omitting the other elements that are not related.

Towards this, the knowledge engineer analyses the DISPLAN template to identify the supporting activities to achieve that goal and the role(s) responsible for each of them. All these knowledge elements in this process serve as common elements of the *goal model*. All subsequent instances will conform to the common elements of the customized template. In the final customization step, the knowledge engineer marks every knowledge element to highlight the likely MOF abstraction layer of the element (M0 or M1). For instance, the main goal "*Road and Traffic Control*" is annotated *M1* as it represents the objective to be strived for, and all its remaining sub-goals will be marked for *M0*. The customized *goal model* constructed following the MOF framework is shown in Figure 5 (Note, only *goal model* is shown in this stage due to space limitations).

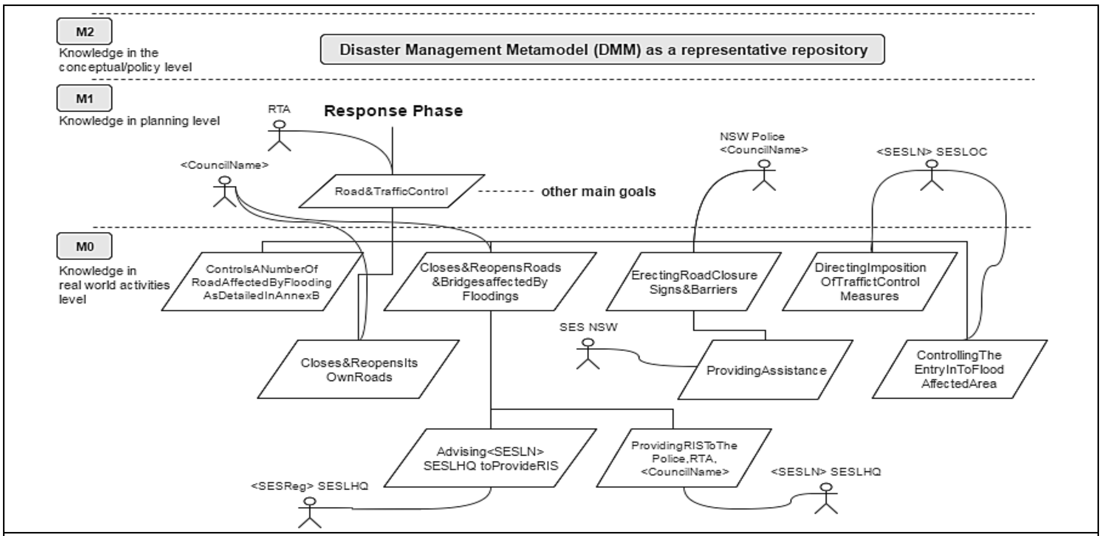

Figure 5. A customized goal model of the DISPLAN template of the SES NSW for a main goal "*Road and Traffic Control*", an example.

Stage 2: Generating Agent-Based Model DISPLANs

Each of the customized ABMs DISPLAN knowledge templates instantiates a particular ABM plan based on the local wisdom where it will be implemented to. In this case study, all NSW regions and their municipalities can adopt the same DISPLAN knowledge template to produce each of their local DISPLANs (local flood plans). The template is used to instantiate local plans efficiently that share the various commonalities of knowledge across all areas within NSW with adjustable local context. Within state of NSW, there are 141 municipalities within 18 regions (SES NSW Australia, 2016). In this case study, the Wollongong municipality is employed as an exemplar.

Generating the goal model. This model fundamentally represents the same knowledge as its class (customized one), but in the context of the Wollongong municipality. The knowledge engineer substitutes all the knowledge classes from the customized version with the one representing the Wollongong municipality, accordingly. This then becomes the *goal model* of Wollongong flood DISPLAN knowledge as drawn in Figure 6.

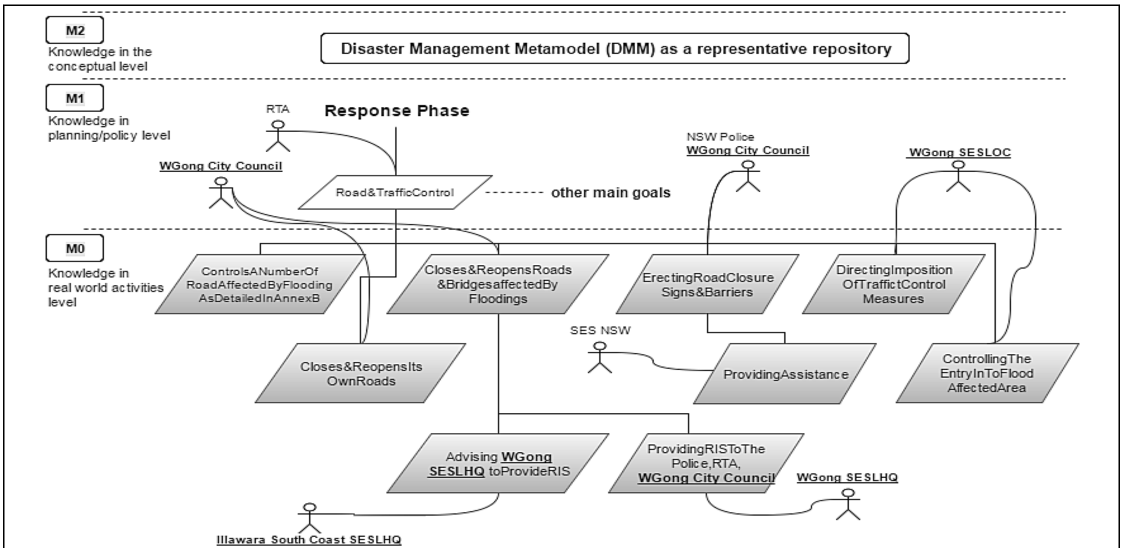

Figure 6. The *goal model* of Wollongong flood DISPLAN knowledge generated from the customized one of the SES NSW template for f a main goal "*Road and traffic control*".

Some of the knowledge elements are substituted to represent the characteristics of the Wollongong City whereas others generic ones remain applicable. All the knowledge elements in the bracket "< >"

are substituted with the ones represented the knowledge of the Wollongong municipality. A knowledge engineer goes through all the knowledge element classes of the customized *goal model* to generate the instance one. Once it is in place then it is ready to be transferred into the repository (Note that only a generating process of *goal model* is shown due to space limitations). In Table 1, the substitution process is shown. All the knowledge elements in the bracket "< >" are substituted with the ones represented the knowledge of the Wollongong municipality. A knowledge engineer goes through all the knowledge element classes of the customized *goal model* to generate the instance one. Once it is in place then it is ready to be transferred into the repository.

DISPLAN Knowledge template	**Wollongong City DISPLAN instance**
The ~~**<SESLN>**~~ **SES Local Operations Controller** may direct the imposition of traffic control measures	<SESLN> = SES Local Name = Wollongong City SES Local Operations Controller
~~**<SESLN>**~~ **SES Local Headquarter** provides Road Information Service (RIS) to the Police, RTA and the ~~**<CouncilName>**~~	<CouncilName> = Wollongong City Council
Controls a number of ~~**<roads>**~~ within the ~~**<council area>**~~ that are affected by flooding as detailed in annex B	Roads of Wollongong City: Princess Highway at Kembla grange; West Dapto Road at Dapto Creek and junction at Sheaffes Road; Cordeaux Road, Figtree; Princes Hwy, Unanderra (between Cordeaux Rd & Farmborough Rd); Bellambi St, Tarrawanna (Southern End), etc; Council area of Wollongong City: Austinmer, Coledale, Thirroul, Bulli, Corrimal, Woonona, etc.
~~**<SESReg>**~~ **SESLHQ**	<SESReg> = SES Regional = Illawara South Coast SES Local Headquarter
~~**<SESLN>**~~ **SESLHQ**	<SESLN> = SES Local Name = Wollongong City SES Local Headquarter
...and so on	

Table 1. Generating process of Wollongong elements based on the customized *goal model*.

Stage 3: Knowledge transfer

There are two activities in this stage, namely: 1) annotating DMM to prepare the repository for the depositing process; and 2) the knowledge transfer process itself. They are both examined as follows:

Annotating DMM concepts with the AO concept

This activity aims to prepare the repository by annotating all the concepts in DMM with the corresponding ones of AO metamodel. This is a one-off process that results in the annotated DMM for all four phases. For the purpose of the case study in this paper, only the annotated DMM-based concept in the Response phase is shown as in Figure 7. A *goal model* will be mapped with a corresponding goal concept through <<*goal*>> to represent the goals to be pursued. Likewise, a *role model* will be mapped with a <<*role*>> concept, *environment model* with an <<*environmentEntity*>> concept, and so on. To describe hierarchy level among agents involved in a DISPLAN (as described in *organization model*) the domain properties of the agent are added as: *isPeer*, representing agents in the same hierarchy level; *Controls* and *IsControlledBy* represent where an agent controls another agent or is controlled by others. Interaction in the *interaction model* between agents to pursue goal(s) is described by adding the relations: *ParticipatesIn* that describes agents participated in a particular activity or in other words, that is described activity that need to be pursued that *Involves* agents. As mentioned, although this annotating process is prepared only one time, however, a knowledge engineer can always revisit the product to revise as necessary. Once the annotated DMM-based repository is considered ready, the transfer process can be enabled.

Transferring the DISPLAN knowledge into the repository

Once the annotated repository is in place, the transfer process commences. The seven ABMs of the Wollongong flood DISPLAN knowledge from the Stage 2 are transferred into the annotated DMM-based repository. This maps each of the ABMs of Wollongong DISPLAN knowledge to each of their corresponding concepts in the DMM-based repository. With respect to the MOF framework, essentially, the process is that the knowledge in the *M0* layer is modelled and structured in *M1* layer is transferred to its appropriate metamodel-based repository in *M2* layer, ((*M0*→*M1)*→*M2*). This process is intermediated by a knowledge engineer based on semantic meaning between each of the ABMs of DISPLAN knowledge and the most possible appropriate concept in the repository. In this research, a graphical-based tool is created to illustrate this knowledge transfer mechanism in a way it can be understood easily. The ABMs are made available in XML and they are the input to a MySQL database. MySQL is used in the prototype as it is a powerful, widely-used, open source database that harnesses a web-based technology to connect client requests to the server. Apache web server technology used in most web servers around the world, is chosen. In the repository, the three components: DM phases, the MOF framework and the ABMs construct the knowledge in a three-dimensional (3D) structure which allows the knowledge to be drilled down or rolled up easily in real time during the DM activities. To complete the 3D knowledge structure, these three stages are undertaken iteratively. Eventually, this knowledge structure allows the knowledge to be reused by pinpointing the appropriate knowledge through each cube of the structure as necessary.

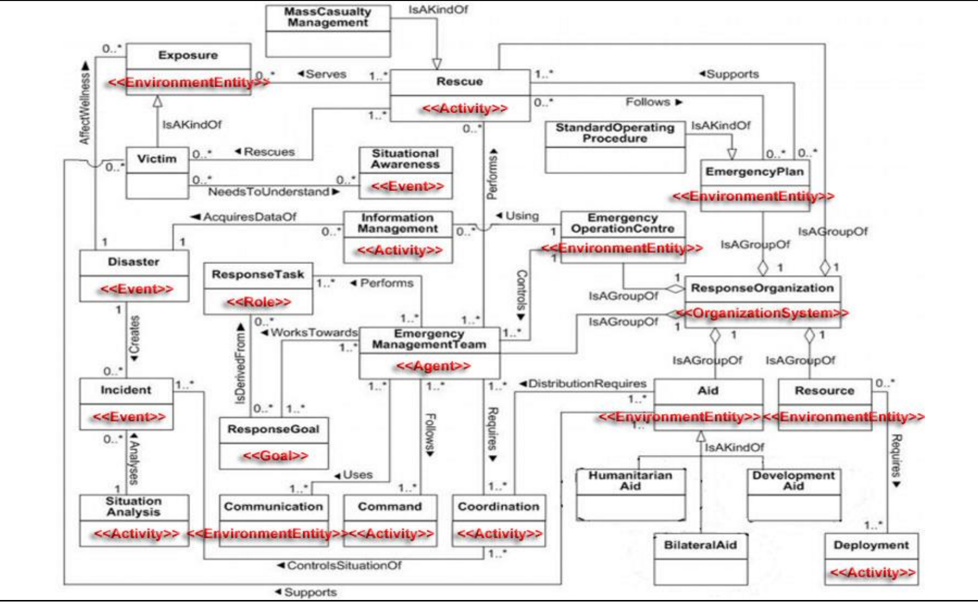

Figure 7. DMM-based concepts annotated with AOSE metamodel concepts in the Response-phase

Two scenarios can arise during the transfer: (1). If there is only one appropriate annotated DMM-based concept in the repository to which an ABM is match with, then the transfer process can be proceeded automatically and directly; (2). If there is more than one possible appropriate annotated DMM-based concept in the repository, then a DM expert intervention is required to determine which concept, among all possibilities, is more appropriate for the ABM to be positioned and transferred to. An example of the first scenario is where there is only one <<*goal*>> concept in it. As such, the *goal model* can be transferred directly to that particular concept goal: <<*goal*>> in the repository without any intervention from the knowledge engineer. In scenario 2, however, if there is more than one corresponding DMM-based concept in the repository where the knowledge can be transferred to, then a knowledge engineer intermediates the process by examining semantically the most appropriate concept in the repository that fit for the one of the ABMs. Subsequently, that particular ABM of flood DISPLAN knowledge will be transferred to most suitable concept in the repository. For instance, the concept in the repository representing environment entity is <<*EnvironmentEntity*>>. As can be seen in the annotated DMM-based repository for Response-phase in Figure 7, there are 11 concepts representing <<*EnvironmentEntity*>>, they are: *Aid, Humanitarian Aid, Bilateral Aid, Development Aid, Resource, Emergency Plan, Standard Operating Procedure, Emergency Operating Centre, Exposure, Victim* and *Communication*. Therefore, in this case, a knowledge engineer will judge and position the *environment model* of the Wollongong DISPLAN knowledge to be mapped to one of them that is considered the most appropriate one, semantically. For instance, for this typical knowledge, "*List of roads and bridges affected by flooding used by the roles to achieve the goal*" from the *environment model* of Wollongong flood DISPLAN knowledge. Of all possibilities semantically, the *Resource* concept "*Personnel and major items of equipment, supplies, and facilities available or potentially available for assignment to incident operations and for which status is maintained*" is considered as the most appropriate. Once the knowledge transfer process is completed, then the knowledge in the repository is ready for use for decision-making mechanism.

As indicated previously that a prototype of the developed framework is implemented utilizing web-based technology. The system architecture is drawn in Figure 8. As can be seen, the prototype comprises two primary interfaces, namely (1) Agent-Oriented Analysis (AOA) tool, for analysing and modelling the knowlede elements out of the DISPLAN. This is esentially the customising prpocesses of ABMs and generating process of a unique plan. The output of this tool is a collection of *M0-M1* knowledge elements of seven ABMs being structured in a XML file that is ready to be transformed to the second tool; (2) Disaster knowledge management tool. This tools is used to manage the transferred knowledge from the first tool into the repository. Utilizing tool, mapping processes of the knowledge elements from the ABMs (*M0-M1*) to their appropriate concepts in *M2* take place.

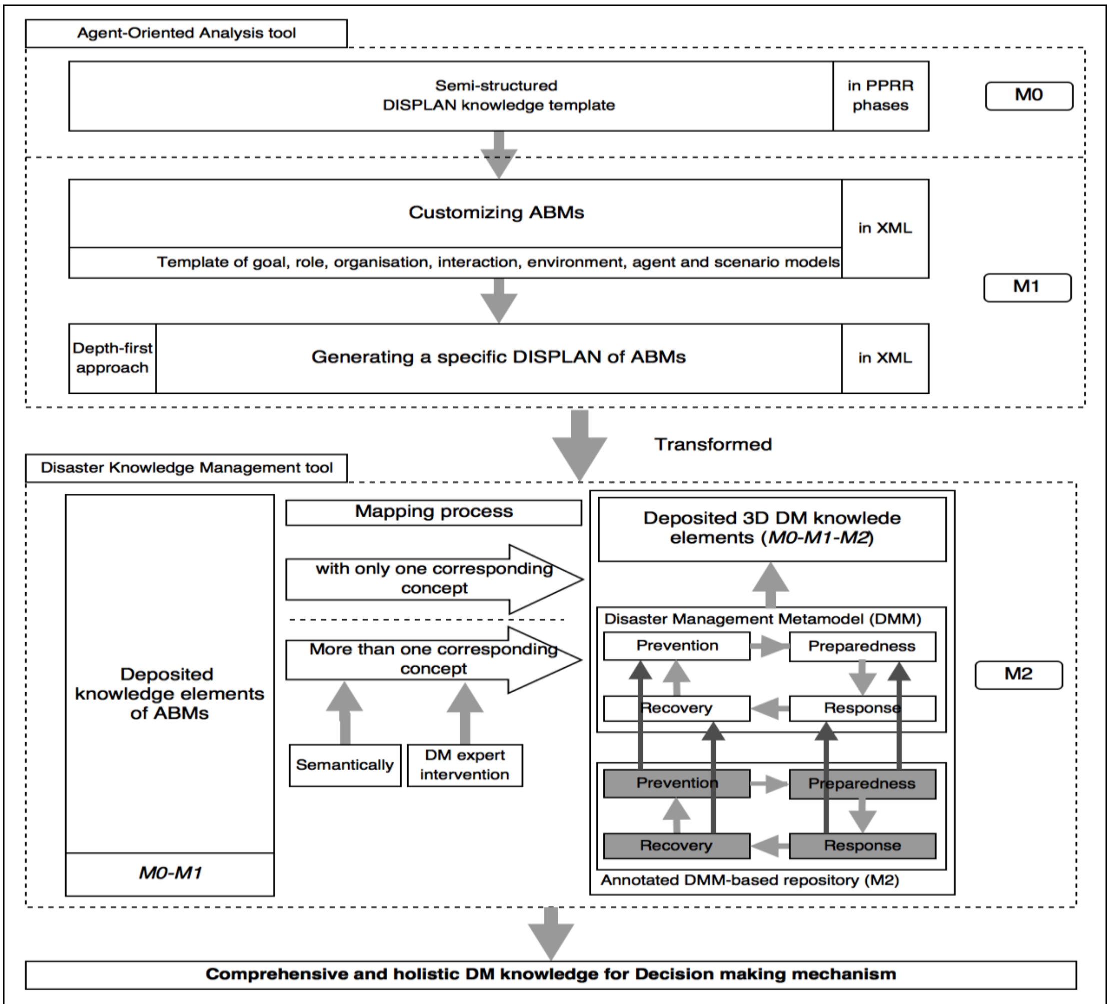

Figure 8. System architecture of the developed framework

Discussion, conclusion and future work

The knowledge analysis framework described in this paper addresses the challenges of converting DM knowledge into a format that can be more easily shared and reused by others in a typical DM resilience framework. The Design Science Research (DSR) methodology (Hevner et al., 2004) frames this research activity (Gregor & Hevner, 2013). Supporting its initial validations (Inan et al., 2015, 2016), this research contributes in (1) Developing a knowledge analysis framework in DM as the built artefact. The framework shows in detail the knowledge conversion process compiled in semi-structured DISPLAN to the DMM-based repository; (2) Harnessing the knowledge template instead of a particular local DISPLAN effectively and efficiency increases the most essential and relevant knowledge dissemination. In the DM context, this contributes to develop the DM resilience endeavors; (3) Introducing the depth-first approach for analyzing and modelling stages. By adopting this approach, the analysis process can be performed more efficiently as it can be done parallel and distributed by some modelers at the same time. The first-depth approach shows not only where to start but most importantly the details of how to do the AB modelling. As in the DSR, once built, the evaluation of the artefacts is conducted at the first place. In this research, it follows the evaluation approach of "*ex ante*" and "*ex post*" as discussed in here (Pries-Heje et al., 2008). By adopting this evaluation strategy (Prat et al., 2014), the research has successfully demonstrated that the use of template has not only the significant impact of the framework effectivity and efficiency but also this can boost the DM resilience endeavors by helping DM authoritative agencies to developed local wisdom-based DISPLANs.

Our developed framework theoretically contributes in the area of knowledge management in disaster management domain. In particular, we develop a framework in which fuzzy and intertwine knowledge being structured in semi-structured DISPLAN format can be disentangled to be understood by stakeholders who have no DM domain expertise. ABMs facilitate this to happen. As it is subsequently stored in a DMM-based repository, it can be shared and reused for the typical DMs. Our developed framework also demonstrates its capability in a way that the knowledge elements extracted from the DISPLAN can be mechanized utilizing MOF to be positioned in DM timeline, in particular for decision making, planning/policy and real world layers. Thus, in a case of disaster, the stakeholders in each of these layers will be automatically guided by the essential and relevant knowledge at any point of the time line to react and pro-act towards it. Put simply, each of the stakeholders knows how to appropriately response in a disaster event in any point of the timeline. All these artefacts resulted are then evaluated rigorously to complete the methodological cycle being guided by DSR in Information System for their efficacy and utility.

To the best of our knowledge, although ABMs have been recognized in DM domain, in fact, there are many and various researches have been devoted in modelling DM domain using ABMs, this work is the first in adopting ABM in descriptive fashion to analyze and model the complex knowledge out of the domain. We have presented in the previous sections that the essential and complex constructs of DM domain in which ABMs are capable to represent them. Therefore, it is not surprising that they can lend themselves to represented each other. Our work also shed light the practical implication in a way that the framework presents the guidance for the stakeholders, in particular the DM authoritative agencies, to complete and improve the incompleteness and fuzziness respectively of the knowledge elements in their existing DISPLAN. This is because element structures in the ABMs allows the missing and incomplete knowledge elements in the DISPLAN to be identified for a comprehensive and holistic arrangement. This is due to DMM-based metamodel structure that enables the arrangement as that particular structure provides the most essential and relevant concepts thoroughly of the domain and their relationships.

The framework is applied on converting DISPLAN template of the SES NSW Australia to DMM. This process shows how the Wollongong Municipality (of NSW) flood DISPLAN knowledge can be effectively and efficiently generated from its template. Knowledge that is modelled from the SES DISPLAN can instantiate local plans for other areas while maintaining accuracy can context. Thus, instead of eliciting the relevant knowledge from scratch, the Wollongong city can focus to this approach to generate its comprehensive DISPLAN knowledge subsequently mechanizing a better decision making process for a flood disaster. Once the knowledge is deposited into the repository, all the corresponding stakeholders can see the relationships they have with other entities in achieving goals or undertaking tasks across the various phases of DM. The stakeholders can reconstruct the knowledge based on the context of the ongoing event. DMM guides the stakeholders to identify the relevant concepts based on the relations in the DMM. For example, Figure 7 shows that there are eight additional concepts directly related to the *EmergencyManagementTeam* that are necessary to get a comprehensive understanding of the task. They are *Coordination, Command, Communication, ResponseGoal, ResponseTask, Rescue, EmergencyOperationCentre* and *ResponseOrganisation*. This means that this structure enables the stakeholders to obtain all insight ideas thoroughly to response to one particular concept and all its related ones (these eight concepts).

This is due to DMM-based metamodel arrangement that allows this to happen as it constitutes (or at least is envisaged) complete collections of the most relevant and essentials concepts of DM and how they are related. Thus, comprehensively for one particular scenario, all the related knowledge concepts to it can be identified efficiently. By employing MOF framework, the developed framework also facilitates each of these knowledge concepts to be holistically drilled down into lower layers representing knowledge in the planning/policy and real world activities. As such, this structure provides flexibilities for the stakeholders to identify the most suitable knowledge elements based on the urgency of an event in the DM timeline. This approach, by far, contributes in addressing the strict delineation of the existing PPRR framework. In other words, in a case of disaster, the corresponding stakeholders can be immediately equipped with all relevant concepts comprehensively and their details know-how, know-what, know-why and know-with holistically.

A case in point to illustrate our approach can be referred to a very recently devastated and deadly flood disaster that hit New South Wales State of Australia (ABC News, 2017; Gregory, 2017). As this situation triggers the DISPLAN activation, the authoritative agency to combat the disaster, SES NSW, will automatically refer to the existing DISPLAN as a guidance to carry out the DM activities. Based on the situational analysis, the agency issued an "evacuation warning" to all the impacted areas (NSW SES, 2017). This means that all the people who are living in the flood affected areas need to evacuate as early as possible to the designated evacuation centers. Utilizing our framework, once the evacuation is the goal that needs to be achieved, it means that the evacuation will be associated to the *ReponseGoal* construct in the repository. The authoritative is then able to identify other related concepts directly correlated to that particular construct, namely: *EmergencyManagementTeam* as <<*agent*>> to pursue the goals, and *ResponseTask* as <<*role*>> to define all the responsibilities of involved agents in pursuing the goals. The knowledge elements structured in the repository also allows the knowledge for the planning/policy layer, for instance, where is the evacuation centers, who help the evacuation, particular for those with disabilities, who will provide food in the evacuation center, etc. As for the real world activities, those who are on the front line who are equipped with this typical knowledge structure will use that without requiring any deduction process.

The knowledge analysis framework contributes to this by providing the knowledge holistically from its conceptual to real world activities. By developing the DMM based repository and using ABM, gaps where actions or tasks have not been planned for can be elicited. This presents opportunities to improve the conceptual completeness of the DM by organizations.

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